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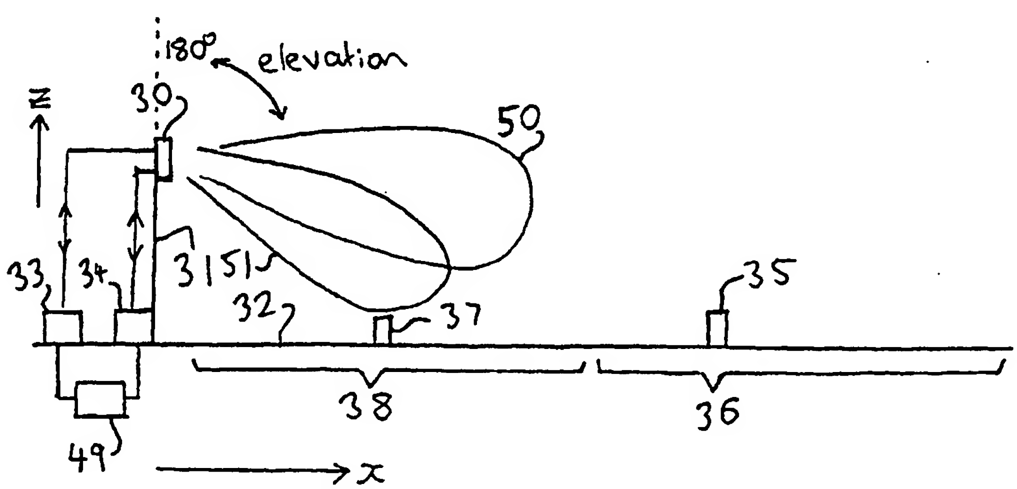

(57) Abstract: A method of communicating between a multi-beam phased array antenna (30) and a plurality of mobile communication devices (35, 37) located at different distances from the antenna. The antenna comprises a plurality of antenna elements (39) mounted at different heights. The method comprises communicating between the antenna and the further of the mobile communication devices using an upper beam (50); and communicating between the antenna and the closer of the mobile communication devices using a lower beam (51) which is downtilted with respect to the upper beam. A method of communicating between a multi-beam phased array antenna (30) and a plurality of mobile communication devices. The method comprises generating a first carrier signal having a first frequency f1; modulating the first carrier signal to generate first down-link signals; transmitting the first down-link signals from the antenna to the mobile communication devices in a first beam; generating a second carrier signal having a second frequency f2 which is different to the first frequency; modulating the second carrier signal to generate second down-link signals; and transmitting the second down-link signals from the antenna to the mobile communication devices in a second beam which is directed at a different angle to the first beam.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

TELECOMMUNICATION ANTENNA SYSTEM

The Technical Field

The present invention relates to a telecommunication antenna system; a method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices; and a phased array feed network.

Background of the Invention

A conventional cellular telecommunication antenna system is shown in Figure 1. An antenna 1 is mounted on a mast 2 and connected to a transceiver 3. The antenna 1 has a downtilted radiation pattern 4 which covers a cell 5 on the ground 6. The transceiver 3 transmits down-link signals 7 to mobile communication devices (hereinafter referred to as "mobiles") 8 in the cell 5, and also receives up-link signals 9 from the mobiles 8. The transceiver 3 communicates with a number of mobiles in the cell 5 using a suitable multiple access method. Examples are frequency division multiple access (FDMA), code division multiple access (CDMA), time division multiple access (TDMA) and spatial division multiple access (SDMA).

When the number of mobiles in the cell 5 reaches an upper limit (depending on the amount of interference between mobiles), no further mobiles can be serviced. A conventional solution to this problem is illustrated in Figure 2. If sufficient space is available on the mast 2, a second antenna array 10 is mounted below the antenna array 1, coupled to a respective transceiver 11 coupled with a power control system 12. The radiation pattern of the array 1 is steered as shown at 13 to illuminate an outer cell 14. The radiation pattern 15 of the

second array 10 is downtilted to illuminate an inner cell (or microcell) 16. The power control system 12 reduces the signals received and transmitted by antenna array 10 in order to prevent overlap between the two cells. The site shown in Figure 2 is conventionally known as an "umbrella site".

An alternative solution is shown in Figure 3. In this case, the radiation pattern of the antenna array 1 is downtilted as indicated at 17 to illuminate a smaller cell 18, and an additional antenna array 19, mast 20 and transceiver 21 are installed to service a second cell 22.

By splitting the cell 5 into a number of microcells 14,16 or 18,22, a larger density of mobiles can be serviced. However the conventional solutions suffer from various problems. In the solution of Figure 2 an additional antenna array 10 is required. Sufficient room may not be available on the antenna mast 2. Also, the cost of acquiring additional space on the mast 2 may be prohibitive. In the solution of Figure 3 additional property must be acquired to install the second antenna system 19-21. The antenna system 19-21 is also unsightly and expensive to install.

A further conventional system is described in US-A-5,890,067. An antenna produces a number of spaced beam spots. Forward communication channels follow mobile units as they move between beam spots. The precise form of the antenna is not described.

Disclosure of the Invention

An object of the present invention is to address or at least ameliorate the problems of the prior art described above, or at least to provide the public with a useful choice.

According to a first aspect of the invention there is provided a method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices located at different distances from the antenna, the antenna comprising a plurality of antenna elements mounted at different heights, the method comprising communicating between the antenna and the further of the mobile communication devices using an upper beam; and communicating between the antenna and the closer of the mobile communication devices using a lower beam which is downtilted with respect to the upper beam.

According to a second aspect of the invention there is provided a telecommunication antenna system for communicating with a plurality of mobile communication devices located at different distances from the system, the system comprising:

a plurality of antenna elements;

a first transmitter for transmitting first down-link signals;

a second transmitter for transmitting second down-link signals; and

a phased array feed network including

> a plurality of antenna ports each coupled to a respective antenna element,
>
> a first signal port coupled to the first transmitter,
>
> a second signal port coupled to the second transmitter; and
>
> means for providing a phase shift between down-link signals at the antenna ports and down-link signals at the first and second signal ports,

the antenna elements and feed network being configured such that when the antenna elements are mounted, in use, at different heights, each element radiates the first down-link signals in an upper beam towards the further of the mobile communication devices, and radiates the second down-link signals in a lower beam towards the closer of the mobile communication devices, the lower beam being downtilted

with respect to the upper beam.

According to a third aspect of the invention there is provided a telecommunication antenna system for communicating with a plurality of mobile communication devices located at different distances from the system, the system comprising:

a plurality of antenna elements;

a first receiver for receiving first up-link signals;

a second receiver for receiving second up-link signals; and

a phased array feed network including

a plurality of antenna ports each coupled to a respective antenna element,

a first signal port coupled to the first receiver,

a second signal port coupled to the second receiver, and

means for providing a phase shift between up-link signals at the antenna ports and up-link signals at the first and second signal ports, signal ports,

the antenna elements and feed network being configured such that when the antenna elements are mounted, in use, at different heights, each element receives the first up-link signals in an upper beam from the further of the mobile communication devices, and receives the second up-link signals in a lower beam from the closer of the mobile communication devices, the lower beam being downtilted with respect to the upper beam.

A fourth aspect of the invention provides a method of installing a telecommunication antenna system, the method comprising the steps of:

(1) providing an antenna system according to the second or third aspect of the invention; and

(2) mounting the antenna elements at different heights.

The first to fourth aspects of the present invention provide a single antenna array with a multi-beam radiation pattern with relatively

downtilted beams. When provided in a cellular system of the type shown in Figure 1, the cell can be divided into inner and outer cells, each serviced by a respective beam. This increases the number of mobiles that can be serviced in a given area.

The antenna elements may have a variety of configurations. For instance the elements may be arranged in a one-dimensional or two dimensional array. Typically the elements are substantially coplanar. At least two of the elements are arranged in use at different heights so as to provide downtilt between the two beams. In a preferred example the elements are arranged in a substantially vertical one-dimensional array.

The second and third aspects of the invention relate to a transmitting antenna system and a receiving antenna system respectively. In a preferred example the system can both transmit and receive signals.

The means for providing a phase shift typically comprises a plurality of phase shifters, which may be variable phase shifters. Typically the variable phase shifters have relatively movable components which are relatively movable to vary the phase shift. The components may be moved manually. Preferably electromechanical means are provided to move the components, and a controller is provided for supplying drive signals to the electromechanical means to adjust the beam angle of the antenna. An example of a phase shift system of this type is given in WO-A-96/14670.

In accordance with a fifth aspect of the present invention there is provided a phased array feed network including
a plurality of antenna ports;
a plurality of signal ports; and
means for providing a phase shift between signals at the antenna ports and signals at the signal ports,

wherein the number of signal ports is less than the number of antenna ports.

The fifth aspect of the invention provides a feed network which is specially adapted for use in a multi-beam antenna system according to the second or third aspects of the invention. In contrast to conventional feed networks where the number of antenna ports is equal to the number of signal ports, the feed network only requires a limited number of signal ports, equal to the number of beams being serviced.

Typically the number of antenna ports is a factor of 2 (ie., 4,8,16 etc). Preferably the number of signal ports is two. In a particularly preferred example the network has two signal ports and eight antenna ports.

A single-beam antenna system is shown in Figure 13 as a comparative example. An antenna 110 radiates down-link signals in a beam 111. The antenna 110 has a single input port 113 for receiving down-link signals. A pair of modulators 114,115 modulate carrier signals at different frequencies f_1 and f_2 respectively and input the modulated signals to a combiner 112. A problem with the arrangement of Figure 12 is that the combiner 112 introduces a significant signal loss into the system.

A sixth aspect of the invention provides a method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices, the method comprising generating a first carrier signal having a first frequency; modulating the first carrier signal to generate first down-link signals; transmitting the first down-link signals from the antenna to the mobile communication devices in a first beam; generating a second carrier signal having a second frequency which is different to the first frequency; modulating the second carrier signal to generate second down-link signals; and

transmitting the second down-link signals from the antenna to the mobile communication devices in a second beam which is directed at a different angle to the first beam.

A seventh aspect of the invention provides a telecommunication antenna system for communicating with a plurality of mobile communication devices, the system comprising: a multi-beam phased array antenna comprising a plurality of antenna elements; means for generating a first carrier signal having a first frequency; a modulator for modulating the first carrier signal to generate first down-link signals; means for generating a second carrier signal having a second frequency which is different to the first frequency; a modulator for modulating the second carrier signal to generate second down-link signals; a phased array feed network including a plurality of antenna ports each coupled to a respective antenna element, a first signal port coupled to the first modulator, and a second signal port coupled to the second modulator; and means for providing a phase shift between down-link signals at the antenna ports and down-link signals at the first and second signal ports so as to cause each antenna element to radiate the first down-link signals in a first beam, and to radiate the second down-link signals in a second beam which is angularly spaced from the first beam.

The sixth and seventh aspects of the invention remove the need for a combiner 112. Instead, the two signals are input into separate input ports of a multi-beam antenna.

The beams may be seaparate azimuthally but preferably the second beam is downtilted with respect to the first beam. Preferably the antenna comprises a plurality of antenna elements mounted, when in use, at different heights.

The following preferred features may be employed in any of the

aspects of the invention.

Preferably the system/method employs multiplexing and/or demultiplexing so as to communicate with a plurality of mobile communication devices with each beam. The system/method may employ time-division multiplexing, frequency-division multiplexing or code-division multiplexing. In a preferred example code-division multiplexing is used.

Preferably the antenna communicates using both beams simultaneously.

Typically the method further comprises the step of assigning or deassigning a mobile communication device to or from one of the beams when the device moves into or out of a cell associated with the respective beam.

Typically the antenna is one of a plurality of antennas forming a cellular network.

Preferred frequency ranges typically fall between approximately 820 MHz and 5 GHz. For instance the system may operate in a GSM frequency range of 870-960 MHz or a 'third generation' frequency range of 1900-2170 MHz.

Brief Description of the Drawings

An example of the present invention will now be described and contrasted with the prior art systems with reference to the accompanying drawings in which:

Figure 1 illustrates a conventional cellular communication antenna system;

Figure 2 illustrates a conventional "umbrella site" antenna system;

Figure 3 illustrates a pair of conventional antenna systems;

Figure 4 illustrates an example of an antenna system according to the present invention;

Figure 5 illustrates the antenna system of Figure 4 in detail;

Figure 5A illustrates one of the signal paths in further detail;

Figure 6 is a graph illustrating variation of the radiation patterns of the two beams with angular elevation;

Figure 7 is a graph illustrating variation of the relative signal level of the two beams with distance from the antenna system along the x-axis;

Figure 8 is a plan view of a cellular communication network incorporating a number of antenna systems of the type shown in Figures 4 and 5;

Figure 9 is a graphic illustrating down-link sources of interference for a CDMA system;

Figure 10 is a graphic illustrating up-link sources of interference for a CDMA system;

Figure 11 is a graphic illustrating the total interference I_k received by a mobile for a one beam CDMA system and a two beam CDMA system along the $y=0$ and $y=2km$ lines;

Figure 12 is a schematic diagram showing an alternative antenna system using a pair of carrier signal frequencies; and

Figure 13 is a comparative example showing a pair of carrier signal frequencies and a single beam antenna.

Best Mode for carrying out the Invention

Referring to Figure 4, an antenna array 30 is mounted to a mast 31 approximately sixty metres from the ground 32. The antenna array 30 is connected to a first transceiver 33 and a second transceiver 34. The transceiver 33 transmits and receives down-link/up-link communication signals to and from mobiles 35 located in an outer cell 36. The transceiver 34 transmits and receives down-link/up-link communication signals from mobiles 37 located in an inner cell 38. A processor 49 assigns/deassigns mobiles to/from the cells 36,38 based on the signal strength of the up-link signals received from the mobiles. The processor 49 also acts as a down-link power control system for adjusting the power of down-link signals transmitted to the mobiles.

The antenna system is shown in more detail in Figure 5. The antenna array 30 comprises a one-dimensional array (ie a single line) of eight radiating elements 39. The elements 39 are oriented vertically (ie. parallel to the z-axis and the mast 31 shown in Figures 4 and 5). Typically the radiating elements 39 are patch elements although dipoles may also be used. Each radiating element 39 is coupled to a respective antenna port of a beam forming network (BFN) 40. The BFN 40 has a first signal port 41 coupled to the transceiver 33 and a second signal port 42 coupled to the transceiver 34. If adjustable downtilt is required, then eight adjustable phase shifters may be inserted between the hybrid couplers (not labelled) and the eight elements 39. The adjustable phase shifters may be remotely adjustable as described in WO-A-96/14670 to vary downtilt of the

beams.

Each transceiver comprises a respective duplexer 43, 44, transmitter 45, 46 and receiver 47,48. The transmitter 45 receives N down-link signals 60 (where N=number of mobiles currently assigned to outer cell 36). Similarly the transmitter 46 receives M down-link signals 61 (where M=number of mobiles currently assigned to inner cell 38). The receivers 47,48 receive the N (outer),M (inner) up-link signals from their respective cells and output them at 62,63.

The signal channel for the upper beam is shown in detail in Figure 5A. The N down-link signals are each encoded differently according to a CDMA encoding scheme (for example a scheme employing Walsh codes) by an encoder 80. The encoded signals are summed by a summer 81. A carrier signal at frequency f_1 and the output of the summer 81 are input to a modulator 82 which provides a modulated output signal to amplifier 83. The modulated output signal is amplified by amplifier 83 before being transmitted to the duplexer 43. The duplexer 43 comprises a band-pass filter 86, which is set to pass signals in a down-link frequency band centred on f_1. Up-link signals are passed by a band-pass filter 87, which is set to pass signals in an up-link frequency band centred on a second frequency f_2. The up-link signals are amplified by an amplifier 88, demodulated by a demodulator 90 and passed to a signal splitter 89 which extracts the N different up-link signals based on the CDMA encoding scheme.

Although the encoder 80, signal splitter 89, modulator 82 and demodulator 90 are illustrated as part of the transceiver 33 located at the antenna site, it will be readily understood that any or all of these functions may be performed at a location remote from the antenna site.

The BFN 40 is configured as a pair of Butler matrices coupled by

hybrid couplers which divide up-link signals on signal port 41 among the eight antenna ports, with each antenna port having a fixed phase offset with respect to the other output ports. The phases are selected so that the down-link signals on signal port 41 are transmitted in an upper beam having a main lobe 50 (Figure 4) with a footprint defining the outer cell 36. Conversely, up-link signals are received at the signal port 41 from a reception zone defined by the main lobe 50.

Similarly, the BFN is configured so that the down-link signals on signal port 42 are transmitted in a lower beam having a main lobe 51 with a footprint defining the inner cell 38. Conversely, up-link signals are received at the signal port 42 from a reception zone defined by the main lobe 51.

The radiation pattern of the antenna array is shown in detail in Figure 6. Figure 6 shows the variation of the radiation pattern of the two beams with angular elevation (180° elevation being defined as the positive z-direction as shown in Figure 4). It can be seen that the pattern includes an upper main peak 50′ (corresponding with lobe 50) for the upper beam and a lower main peak 51′ (corresponding with lobe 51) for the lower beam. It can be seen from Figure 6 that the lower lobe 51 is downtilted with respect to the upper lobe 50 by approximately 10 degrees. As a result the cell 38 is located radially inwardly of the cell 36.

Figure 7 is a section of the two beam footprints along the x-axis at zero height (the x-axis being shown in Figures 4,8,9 and 10). It can be seen from Figure 7 that the signal 53 from the lower beam is stronger than the signal 54 from the upper beam in the vicinity of the antenna array. As distance from the antenna array increases the situation reverses itself at the crossover point 55.

Let us consider how network capacity will be affected in a CDMA system if the two-beam antenna of Figure 4 is used in the hexagonal cellular network shown in Figure 10. Antennas are located at base stations 70,71,72,73 etc and service inner cells 74 etc (indicated with dark shading) and outer cells 75 etc. In a perfect CDMA system the frequency reuse factor is 1, ie. all base stations and mobiles use the same carrier frequency, and the system capacity is interference-limited. All adjacent base stations are a source of interference for down-link signals and all mobiles in the area create interference for up-link signals.

The power controller allows the signal/(interference+noise) ratio (SINR) to be maximised by reducing the transmitted power from mobiles and thus cutting the interference they create for other users. Mobile radiated power is controlled by the base station this mobile is assigned to.

Mobiles are transferred from one base station to another (hand-off) on the basis of the signal received from the mobile. The following estimation was done using hard hand-off between the inner and outer cells. That is, a mobile is assigned to the inner cell when the signal from the lower beam is greater (ie. to the left of the crossing point 55 in Figure 7) and assigned to the outer cell when the signal from the upper beam is greater (ie. to the right of the crossing point 55). Let us estimate the single cell case first. The configuration of the system considered is shown in Figure 8.

Down-link SINR improvement (single cell)

Down-link interference for mobiles is created by signals radiated from base stations for other mobiles in the cell (see Figure 9).

If two-beam antennas (Figure 4) are used then inner and outer cells can be arranged and some mobiles are assigned by the processor 49 to the inner cell with the base station transmitting to them using the lower beam. Thus the number of interferers is reduced.

If the down-link power control system implemented by the processor 49 monitors signal level at the mobile and works perfectly then the amplitude of the signal transmitted from the base station to any mobile is inversely proportional to propagation losses between the base station and mobile

$$P0/L1(\mathrm{x}), \tag{1}$$

where P0 – constant (equals power received by mobile),
L1(x) – propagation loss from base station to mobile located at distance x from base station.

After propagation to the mobile the transmitted level is reduced by propagation loss, so every mobile receives constant power

$$(P0/L1(\mathrm{x}))\cdot L1(\mathrm{x}) = P0 \tag{2}$$

independent of its location in the cell. Signals to all other mobiles are really interferences for this mobile so the total interference received by the k-th mobile is

$$I_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} \frac{P0}{L1(x_j)} \cdot L1(x_k) \tag{3}$$

Equations (1)-(3) above apply to the conventional one-beam antenna system of Figure 1. For the two-beam antenna of Figure 4, two cells are used instead of one. So users are distributed between these cells. For hand-off between inner and outer cells we assume the following

logic: when establishing a link with a mobile, the base station processor 49 estimates propagation losses for both beams using the signal received from the mobile; selects the beam with the higher signal level (hand-off subsystem); and sets the radiated power to provide a minimum satisfactory signal level to maintain quality of the link (using the power-control subsystem mentioned above), thus creating minimum interference for other mobiles. Then the amplitude of the signal intended for the j-th mobile (Figure 9) when radiated from the base station is:

$$\mathrm{Prad}_j = if(L2(x_j) \geq L1(x_j))then\frac{P0}{L2(x_j)}; if(L1(x_j) > L2(x_j))then\frac{P0}{L1(x_j)}$$

(4)

The same signal when received by the k-th mobile (Figure 9) then is:

$$\mathrm{Prec}_{j,k} = if(L2(x_j) \geq L1(x_j))then\frac{P0}{L2(x_j)}L2(x_k); if(L1(x_j) > L2(x_j))then\frac{P0}{L1(x_j)}L1(x_k) \quad (5)$$

The total interference received by the k-th mobile (Figure 9) then is:

$$I_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} \mathrm{Prec}_{j,k} \quad (6)$$

Using expressions (3) and (6) we can estimate the interference level for a one-beam and a two-beam antenna as the mobile moves away from the base station along the x-axis. Results are shown in Figure 11. Moving in the x-direction along the y=0 contour, the interference signal level for the conventional one-beam system of Figure 1 is indicated at 90. For the two-beam system of Figure 4, the interference signal level is indicated at 91. It can be seen that the interference signal level 91 for the two-beam system is significantly lower along the y=0 contour. Moving in the x-direction along the

y = 2km contour, the interference signal level for the conventional one-beam system is indicated at 92. For the two-beam system, the interference signal level is indicated at 93. It can be seen that the interference signal level 93 for the two-beam system is also significantly lower along the y = 2km contour

Up-link SINR improvement (single cell)

For up-link signals, interference for base stations is created by other mobiles (see Figure 10).

If the power control sub-system works perfectly then the level of signal received at the base station from all users assigned to this base station is constant and equal to a minimum level needed to maintain the link. The hand-off system implemented by the processor 49 assigns mobiles to the beam which provides a higher beam signal at the location of the mobile.

For a two beam cell, some users are assigned to the inner cell, which is covered with a higher level than the conventional one-beam system (see Figure 7), so their transmitted power can be reduced, thus decreasing the interference level. If SINR is to be kept constant then the number of users can be increased so improving the system capacity. Let us estimate what gain in capacity can be obtained.

It is necessary to estimate the changes in interference levels for two beams. For the channel associated with the lower beam (footprint L2) the signal received from the j-th mobile is

$$\mathrm{Prec2}_j = if(L2(x_j) \geq L1(x_j))then \frac{P0}{L2(x_j)} L2(x_j); if(L2(x_j) < L1(x_j))then \frac{P0}{L1(x_j)} L2(x_j) \qquad (7)$$

For the channel associated with the upper beam (footprint L1) the signal received from the j-th mobile is

$$\mathrm{Pred}_j = if(L1(x_j) \geq L2(x_j)) then \frac{P0}{L1(x_j)} L1(x_j); if(L1(x_j) < L2(x_j)) then \frac{P0}{L2(x_j)} L1(x_j) \qquad (8)$$

The total interference for the link from the k-th mobile is:

$$I1_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} \mathrm{Prec1}_{j,k} \qquad I2_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} \mathrm{Prec2}_{j,k} \qquad (9)$$

We can estimate improvements in interference levels in the same situation as for the down-link signals using expression (9) with the following results: for the lower beam, channel interference is reduced by 3.6 dB; for the upper beam channel the interference level is reduced by 0.7 dB. The reduction in interference for the inner cell is significant. All estimations were done for uniform distribution of mobiles in the cell in a square grid separated by 40 m (indicated at 76 in Figure 8). The improvement will be greater if mobiles are concentrated close to the antenna location.

An alternative system is shown in Figure 12. The system is similar to the system shown in Figure 5, and identical reference numerals are used where appropriate. Only the transmitter circuitry is shown in Figure 12 for purposes of clarity. However, equivalent receiver circuitry (not shown) will typically also be included.

A signal generator 100 generates a sinusoidal carrier signal at frequency f_1 which is modulated by the modulator 82. The modulator 103 associated with the transmitter 46 for the other beam is provided with a sinusoidal carrier signal from a signal generator 101 with a different frequency f_2. As a result the signals transmitted in the upper and lower beams are at different frequencies. This reduces interference between the two beams.

Where in the foregoing description reference has been made to integers or components having known equivalents then such

equivalents are herein incorporated as if individually set forth.

Although this invention has been described by way of example it is to be appreciated that improvements and/or modifications may be made thereto without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices located at different distances from the antenna, the antenna comprising a plurality of antenna elements mounted at different heights, the method comprising communicating between the antenna and the further of the mobile communication devices using an upper beam; and communicating between the antenna and the closer of the mobile communication devices using a lower beam which is downtilted with respect to the upper beam.

2. A method according to claim 1, the method further comprising multiplexing a plurality of first down-link signals; transmitting the multiplexed first down-link signals in the upper beam; multiplexing a plurality of second down-link signals; and transmitting the multiplexed second down-link signals in the lower beam.

3. A method according to claim 2 wherein the first and second down-link signals are multiplexed by encoding the down-link signals according to a code-division multiplexing scheme.

4. A method according to any one of the preceding claims, the method further comprising demultiplexing a plurality of first up-link signals received in the upper beam; and demultiplexing a plurality of second up-link signals received in the lower beam.

5. A method according to claim 4 wherein the first and second down-link signals are demultiplexed by decoding the down-link signals according to a code-division demultiplexing scheme.

6. A method according to any one of the preceding claims, comprising communicating using the upper and lower beams

simultaneously.

7. A method according to any one of the preceding claims, the method further comprising the step of assigning or deassigning a mobile communication device to or from one of the beams when the device moves into or out of a cell associated with the respective beam.

8. A method according to any one of the preceding claims, wherein the antenna is one of a plurality of antennas forming a cellular network.

9. A method according to any one of the preceding claims wherein the antenna elements are mounted in a substantially vertical orientation.

10. A method according to any one of the preceding claims wherein the antenna elements are configured as a one-dimensional array.

11. A telecommunication antenna system for communicating with a plurality of mobile communication devices located at different distances from the system, the system comprising:
a plurality of antenna elements;
a first transmitter for transmitting first down-link signals;
a second transmitter for transmitting second down-link signals; and
a phased array feed network including
    a plurality of antenna ports each coupled to a respective antenna element,
    a first signal port coupled to the first transmitter,
    a second signal port coupled to the second transmitter; and
    means for providing a phase shift between down-link signals at the antenna ports and down-link signals at the first and second signal ports,
the antenna elements and feed network being configured such that

when the antenna elements are mounted, in use, at different heights, each element radiates the first down-link signals in an upper beam towards the further of the mobile communication devices, and radiates the second down-link signals in a lower beam towards the closer of the mobile communication devices, the lower beam being downtilted with respect to the upper beam.

12. A system according to claim 11 further comprising means for mounting the antenna elements at different heights.

13. A system according to claim 11 or 12 further comprising a first multiplexer for multiplexing a plurality of first down-link signals and passing the multiplexed first down-link signals to the first transmitter; and a second multiplexer for multiplexing a plurality of second down-link signals and passing the multiplexed second down-link signals to the second transmitter.

14. A system according to claim 13 wherein the first and second multiplexers comprise encoders for encoding the down-link signals according to a code-division multiplexing scheme.

15. A telecommunication antenna system for communicating with a plurality of mobile communication devices located at different distances from the system, the system comprising:
a plurality of antenna elements;
a first receiver for receiving first up-link signals;
a second receiver for receiving second up-link signals; and
a phased array feed network including
a plurality of antenna ports each coupled to a respective antenna element,
a first signal port coupled to the first receiver,
a second signal port coupled to the second receiver, and
means for providing a phase shift between up-link signals at the

antenna ports and up-link signals at the first and second signal ports, signal ports,

the antenna elements and feed network being configured such that when the antenna elements are mounted, in use, at different heights, each element receives the first up-link signals in an upper beam from the further of the mobile communication devices, and receives the second up-link signals in a lower beam from the closer of the mobile communication devices, the lower beam being downtilted with respect to the upper beam.

16. A telecommunication antenna system according to claim 15 further comprising means for mounting the antenna elements at different heights.

17. A system according to claim 12 or 16 wherein the means for mounting the antenna elements at different heights comprises an elongate mast and the antenna elements are aligned with the mast.

18. A system according to any one of claims 15 to 17, the system further comprising a first demultiplexer for demultiplexing a plurality of first up-link signals received in the upper beam; and a second demultiplexer for demultiplexing a plurality of second up-link signals received in the lower beam.

19. A system according to claim 18 wherein the first and second demultiplexers are decoders for decoding the down-link signals according to a code-division demultiplexing scheme.

20. A system according to any one of claims 11 to 19, wherein the antenna is adapted to communicate using the upper and lower beams simultaneously.

21. A system according to any one of claims 11 to 20, further

comprising a processor for assigning or deassigning a mobile communication device to or from one of the beams when the device moves into or out of a cell associated with the respective beam.

22. A system according to any one of claims 11 to 21 wherein the antenna elements are configured as a one-dimensional array.

23. A system according to any one of claims 11 to 22 wherein the antenna elements are mounted, when in use, in a substantially vertically orientation.

24. A cellular network comprising a plurality of systems according to any one of claims 11 to 23.

25. A method of installing a telecommunication antenna system, the method comprising the steps of:

(1) providing an antenna system according to any one of claims 11 to 23 or a cellular network according to claim 24; and

(2) mounting the antenna elements at different heights.

26. A method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices, the method comprising generating a first carrier signal having a first frequency; modulating the first carrier signal to generate first down-link signals; transmitting the first down-link signals from the antenna to the mobile communication devices in a first beam; generating a second carrier signal having a second frequency which is different to the first frequency; modulating the second carrier signal to generate second down-link signals; and transmitting the second down-link signals from the antenna to the mobile communication devices in a second beam which is directed at a different angle to the first beam.

27. A method according to claim 26, the method further comprising

multiplexing a plurality of first down-link signals; transmitting the multiplexed first down-link signals in the first beam; multiplexing a plurality of second down-link signals; and transmitting the multiplexed second down-link signals in the second beam.

28. A method according to claim 27 wherein the first and second down-link signals are multiplexed by encoding the down-link signals according to a code-division multiplexing scheme.

29. A method according to any one of claims 26 to 28, wherein the antenna transmits using the first and second beams simultaneously.

30. A method according to any one of claims 26 to 29, the method further comprising the step of assigning or deassigning a mobile communication device to or from one of the beams when the device moves into or out of a cell associated with the respective beam.

31. A method according to any one of claims 26 to 30, wherein the antenna is one of a plurality of antennas forming a cellular network.

32. A method according to any one of claims 26 to 31, wherein the second beam is downtilted with respect to the first beam.

33. A method according to any one of claims 26 to 32 wherein the antenna comprises a plurality of antenna elements mounted at different heights.

34. A telecommunication antenna system for communicating with a plurality of mobile communication devices, the system comprising: a multi-beam phased array antenna comprising a plurality of antenna elements; means for generating a first carrier signal having a first frequency; a modulator for modulating the first carrier signal to generate first down-link signals; means for generating a second carrier

signal having a second frequency which is different to the first frequency; a modulator for modulating the second carrier signal to generate second down-link signals; a phased array feed network including a plurality of antenna ports each coupled to a respective antenna element, a first signal port coupled to the first modulator, and a second signal port coupled to the second modulator; and means for providing a phase shift between down-link signals at the antenna ports and down-link signals at the first and second signal ports so as to cause each antenna element to radiate the first down-link signals in a first beam, and to radiate the second down-link signals in a second beam which is angularly spaced from the first beam.

35. A system according to claim 34 further comprising a first multiplexer for multiplexing a plurality of first down-link signals and passing the multiplexed first down-link signals to the first modulator; and a second multiplexer for multiplexing a plurality of second down-link signals and passing the multiplexed second down-link signals to the second modulator.

36. A system according to claim 35 wherein the first and second multiplexers comprise encoders for encoding the down-link signals according to a code-division multiplexing scheme.

37. A system according to any one of claims 34 to 36 wherein the antenna comprises a plurality of antenna elements mounted at different heights configured as a one-dimensional array.

38. A system according to any one of claims 11 to 23 or 34 to 37 wherein the antenna is suitable for use in a cellular network.

39. A phased array feed network including:
a plurality of antenna ports;
a plurality of signal ports; and
means for providing a phase shift between signals at the

antenna ports and signals at the signal ports,

wherein the number of signal ports is less than the number of antenna ports.

40. A network according to claim 39 comprising a first Butler matrix coupled to a first signal port, a second Butler matrix coupled to a second signal port, and a plurality of couplers coupling the outputs of the first and second Butler matrices.

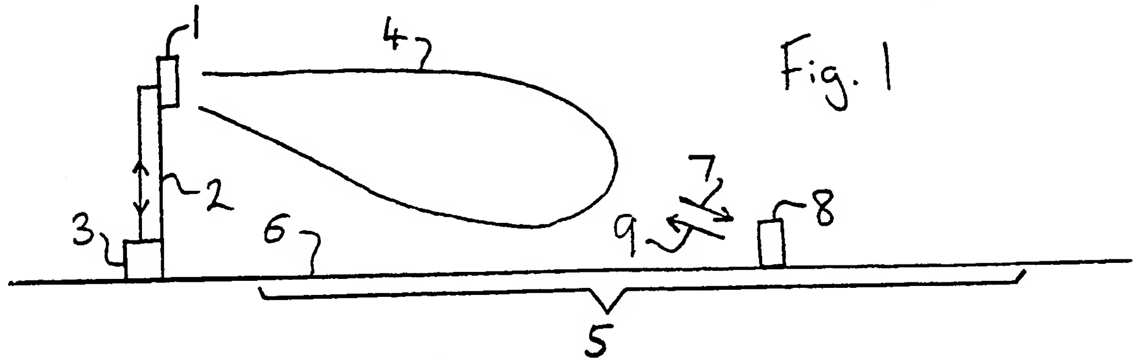


Fig. 1

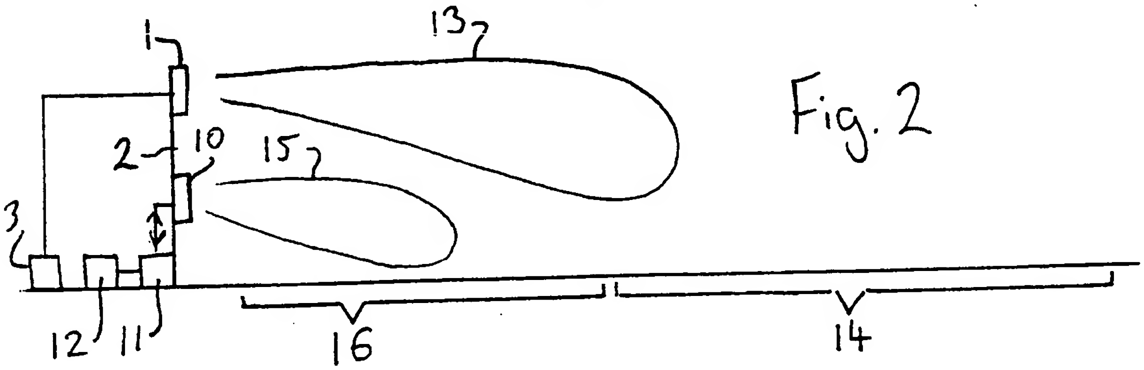


Fig. 2

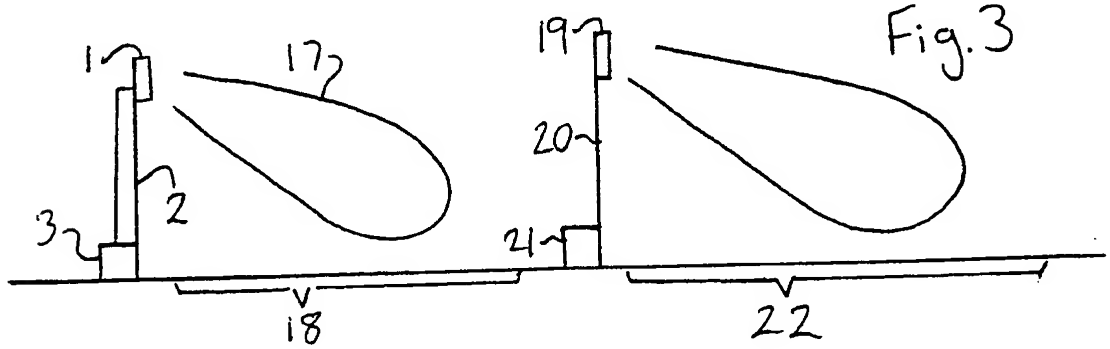


Fig. 3

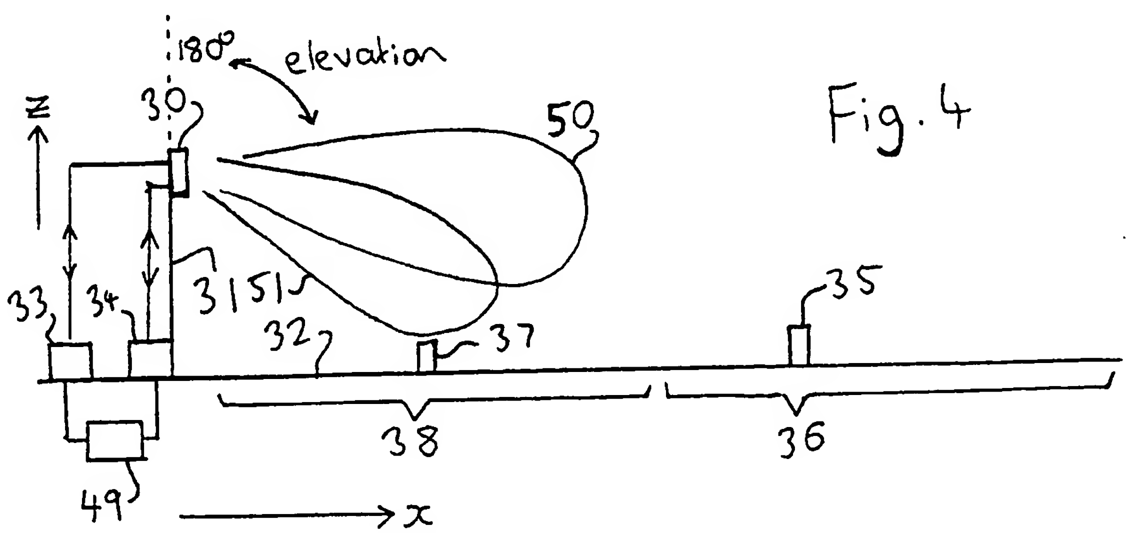


Fig. 4

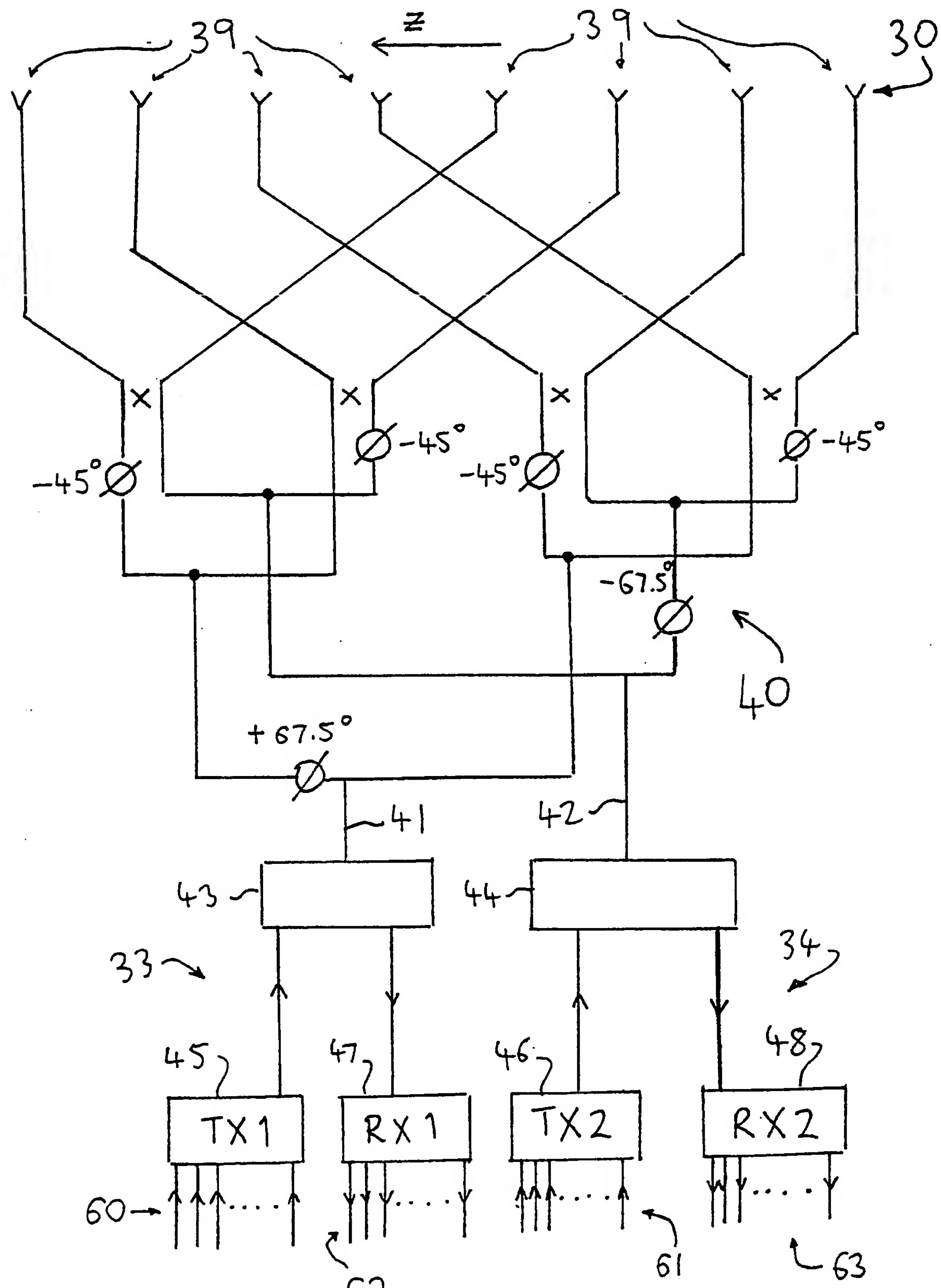
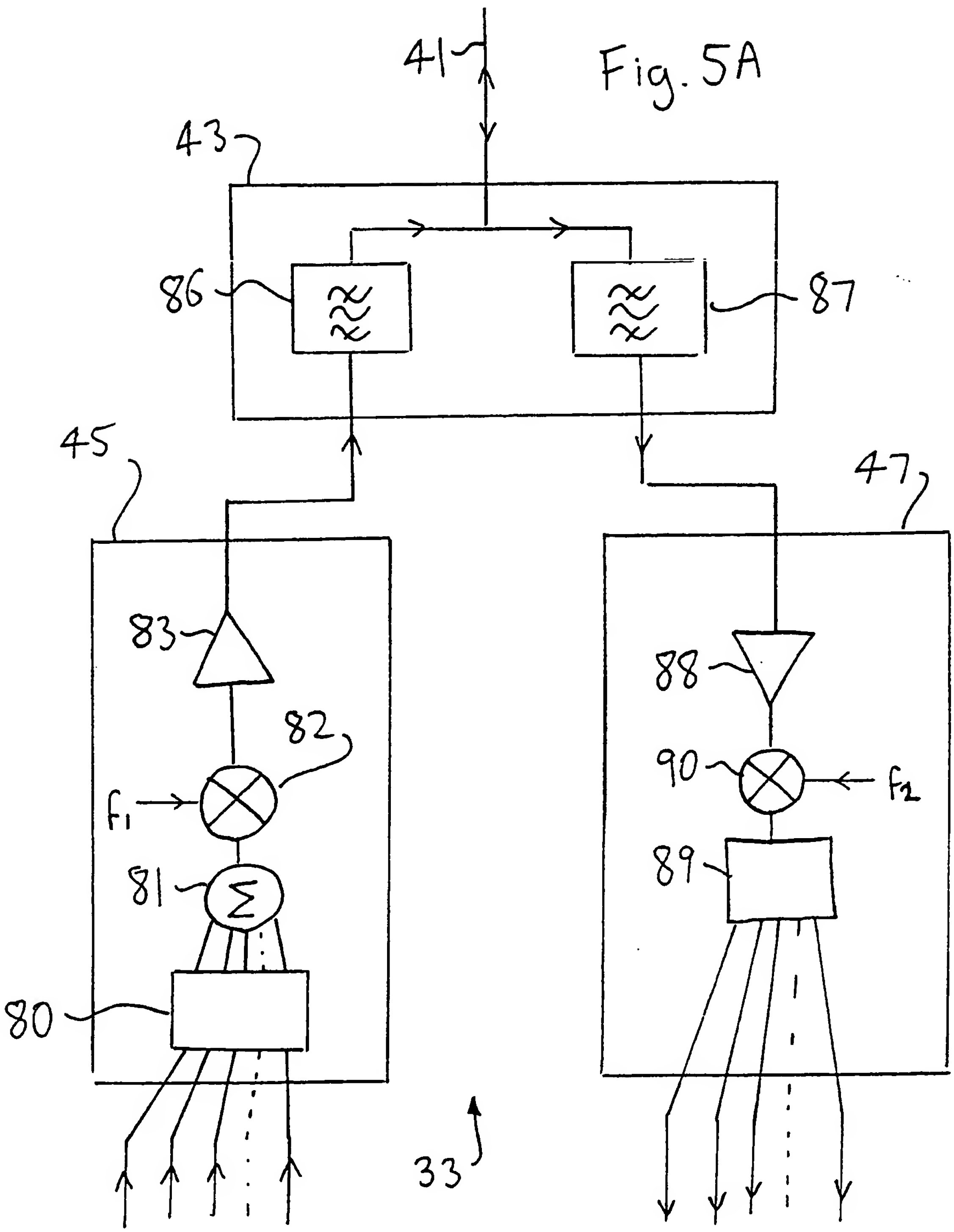

39
z
39
30
-45°
-45°
-45°
-45°
-67.5°
40
+67.5°
41
42
43
44
33
34
45
47
46
48
TX1
RX1
TX2
RX2
60
62
61
63

Fig. 5

Fig. 5A



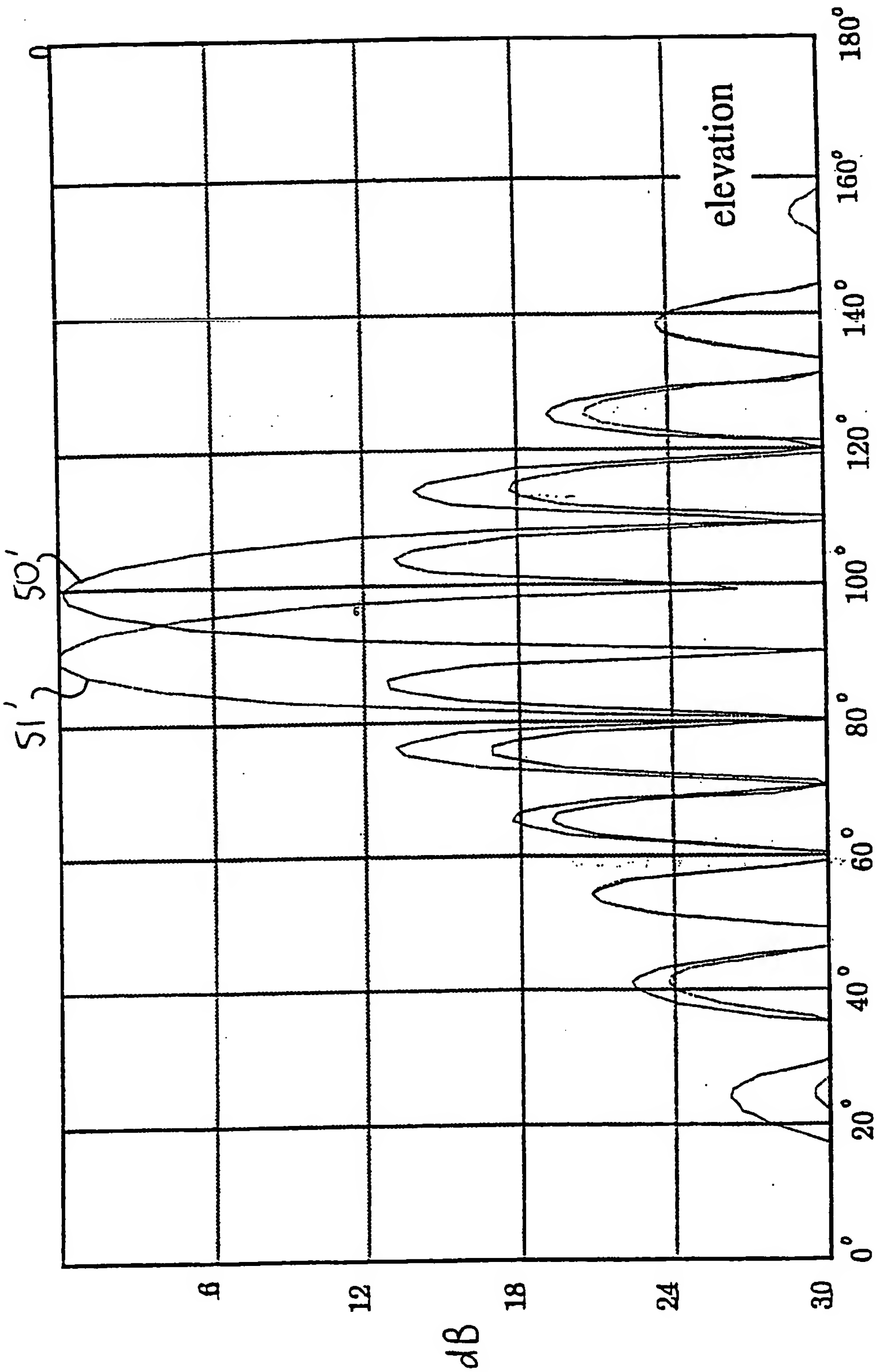


Fig. 6

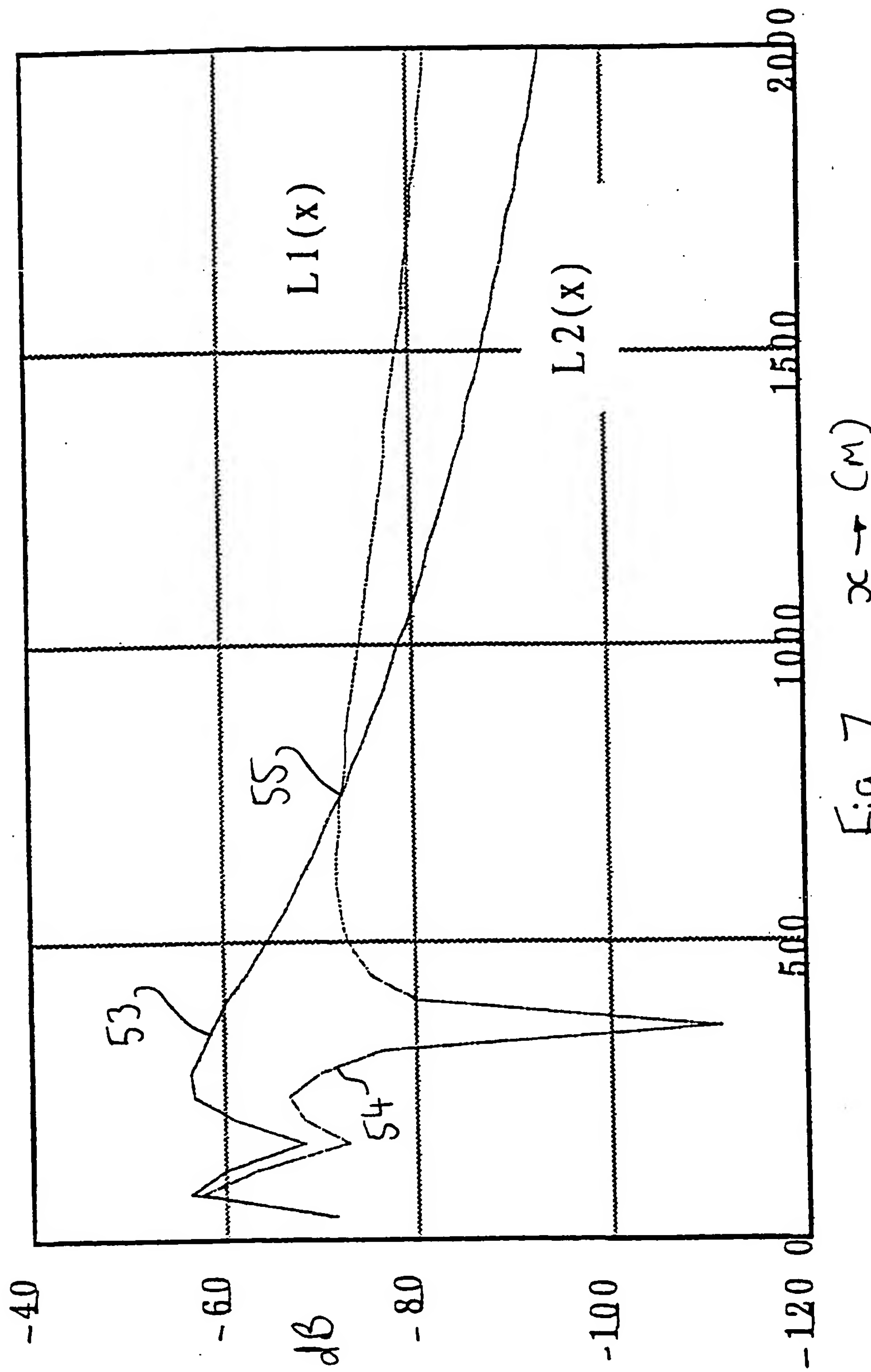


Fig. 7

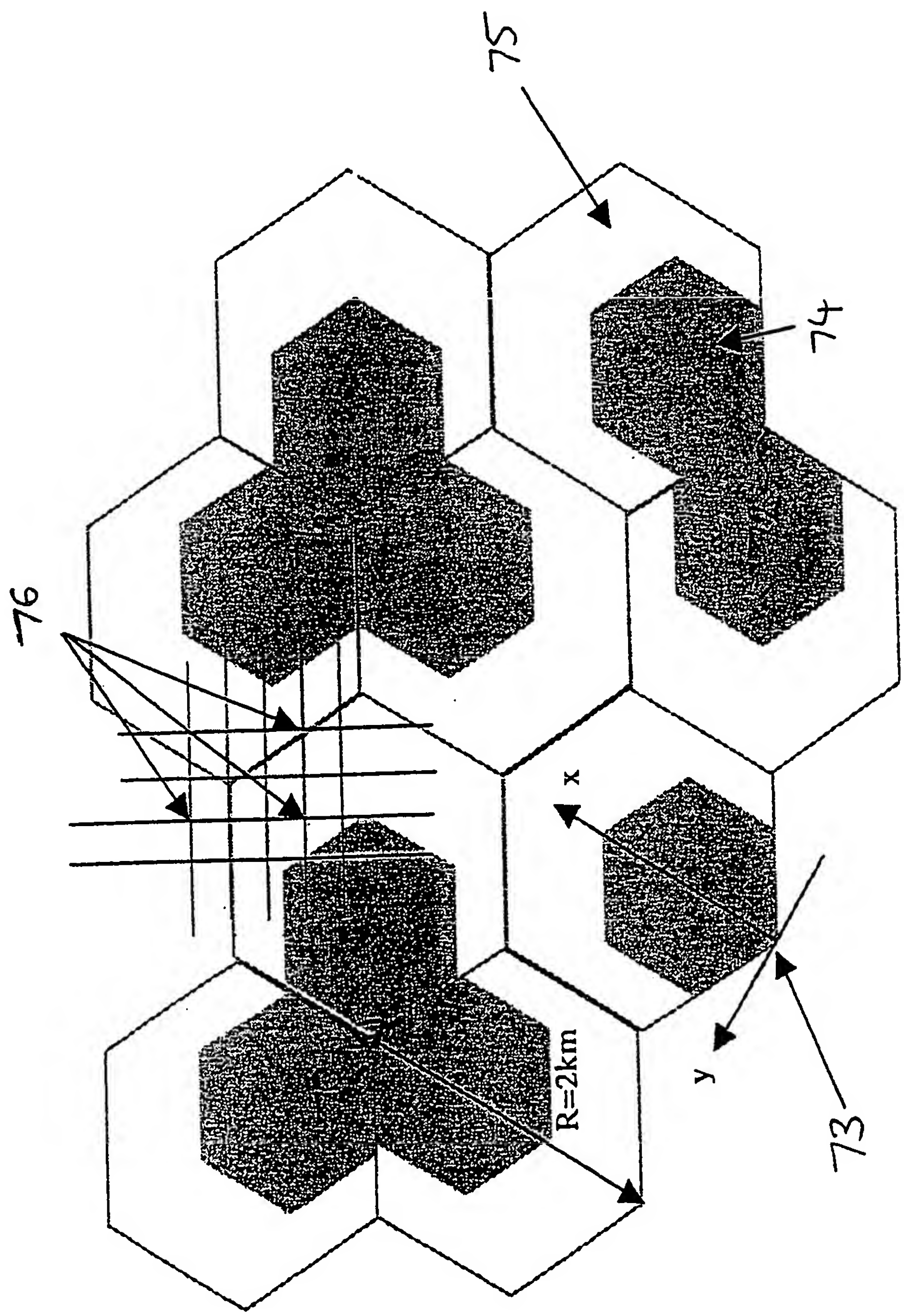


Fig.8

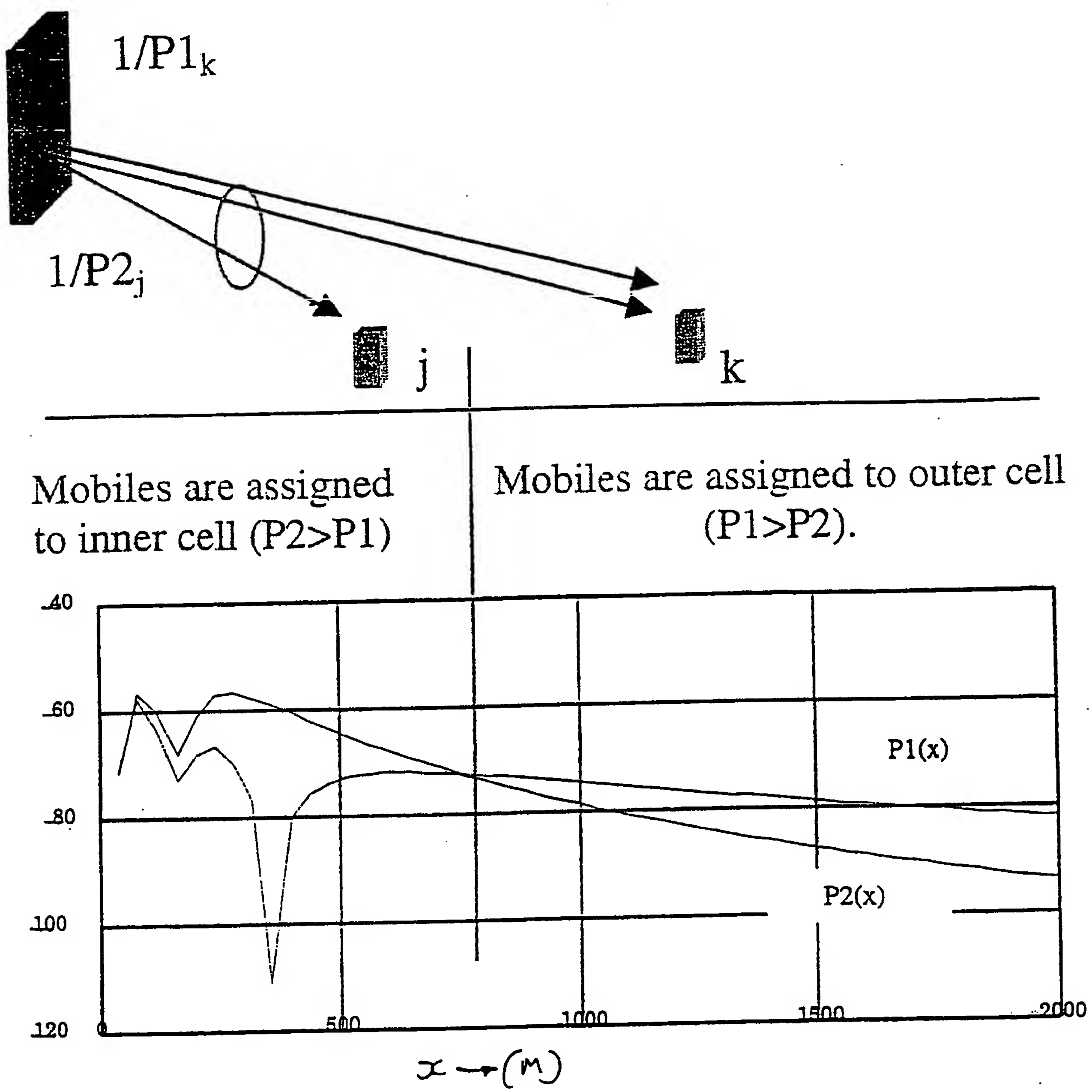
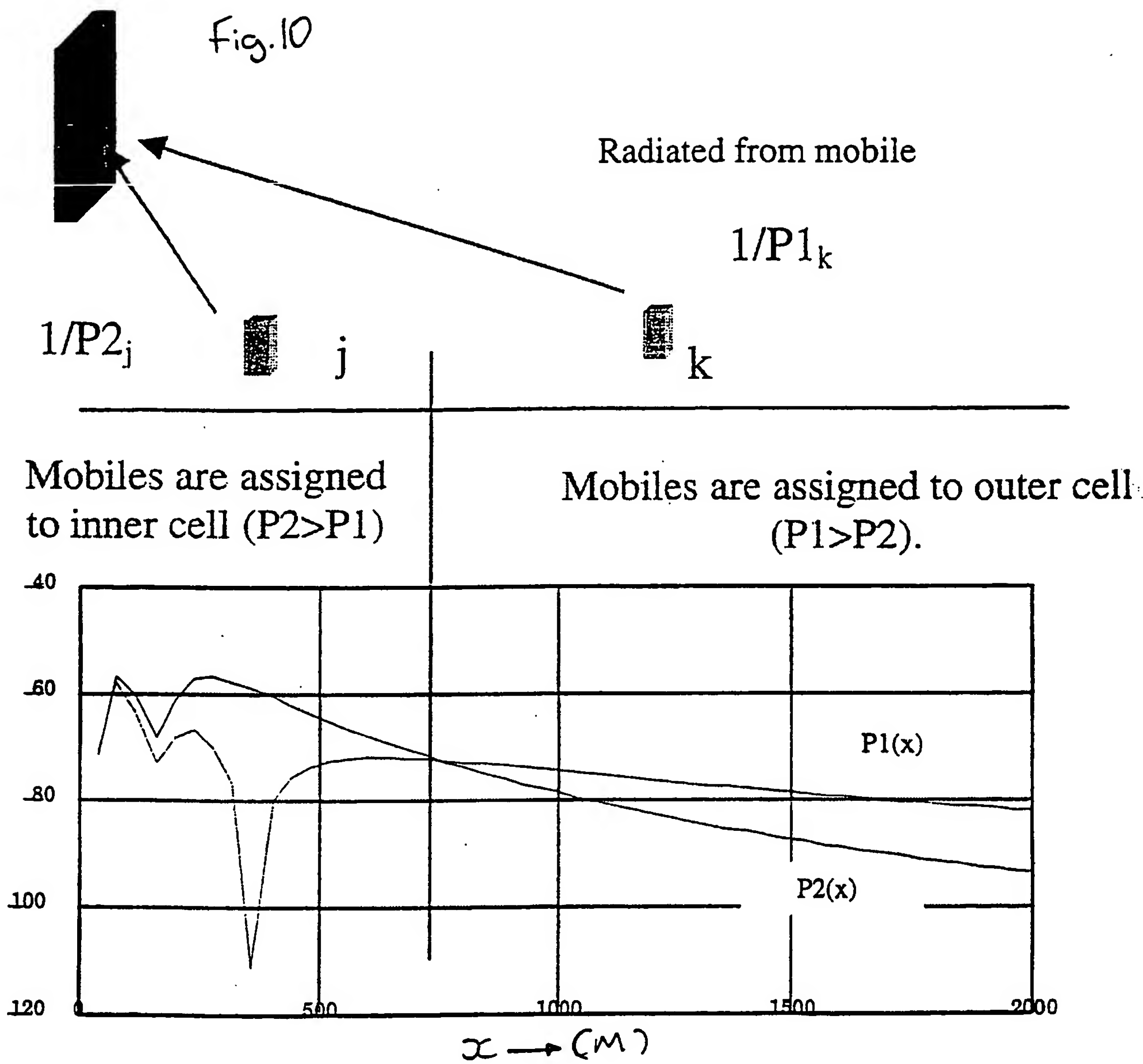

1/P1k
1/P2j
j
k
Mobiles are assigned to inner cell (P2>P1)
Mobiles are assigned to outer cell (P1>P2).
-40
-60
-80
-100
-120
0
500
1000
1500
2000
P1(x)
P2(x)
x → (m)

Fig. 9

Fig.10


Radiated from mobile
1/P1k
1/P2j
j
k
Mobiles are assigned to inner cell (P2>P1)
Mobiles are assigned to outer cell (P1>P2).
-40
-60
-80
-100
-120
0
500
1000
1500
2000
P1(x)
P2(x)
x → (M)

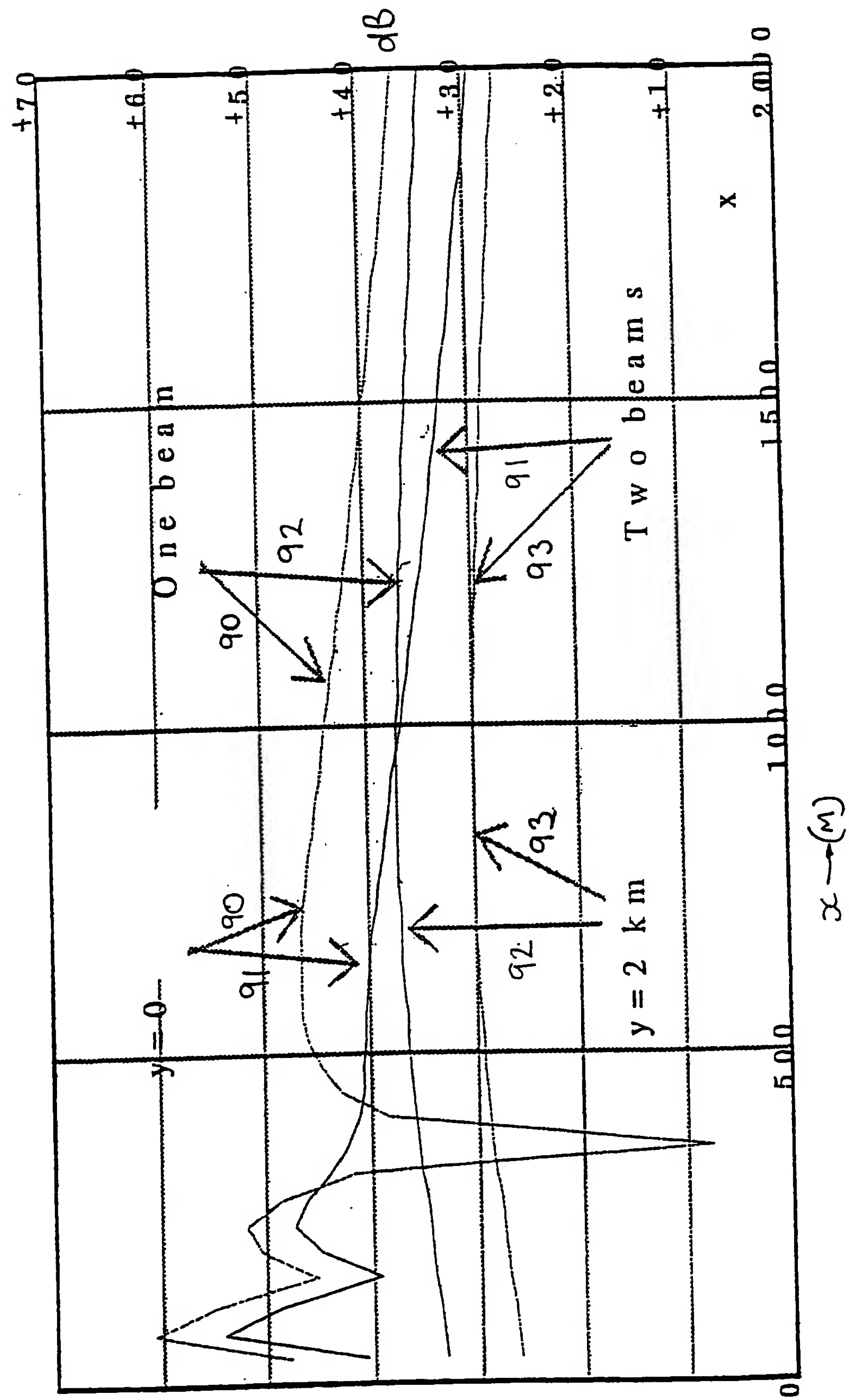

dB
+7.0
+6.0
+5.0
+4.0
+3.0
+2.0
+1.0
0
2000
1500
1000
500
0
x
One beam
Two beams
y = 0
y = 2 km
q0
q1
q2
q3
x → (m)

Fig. 11

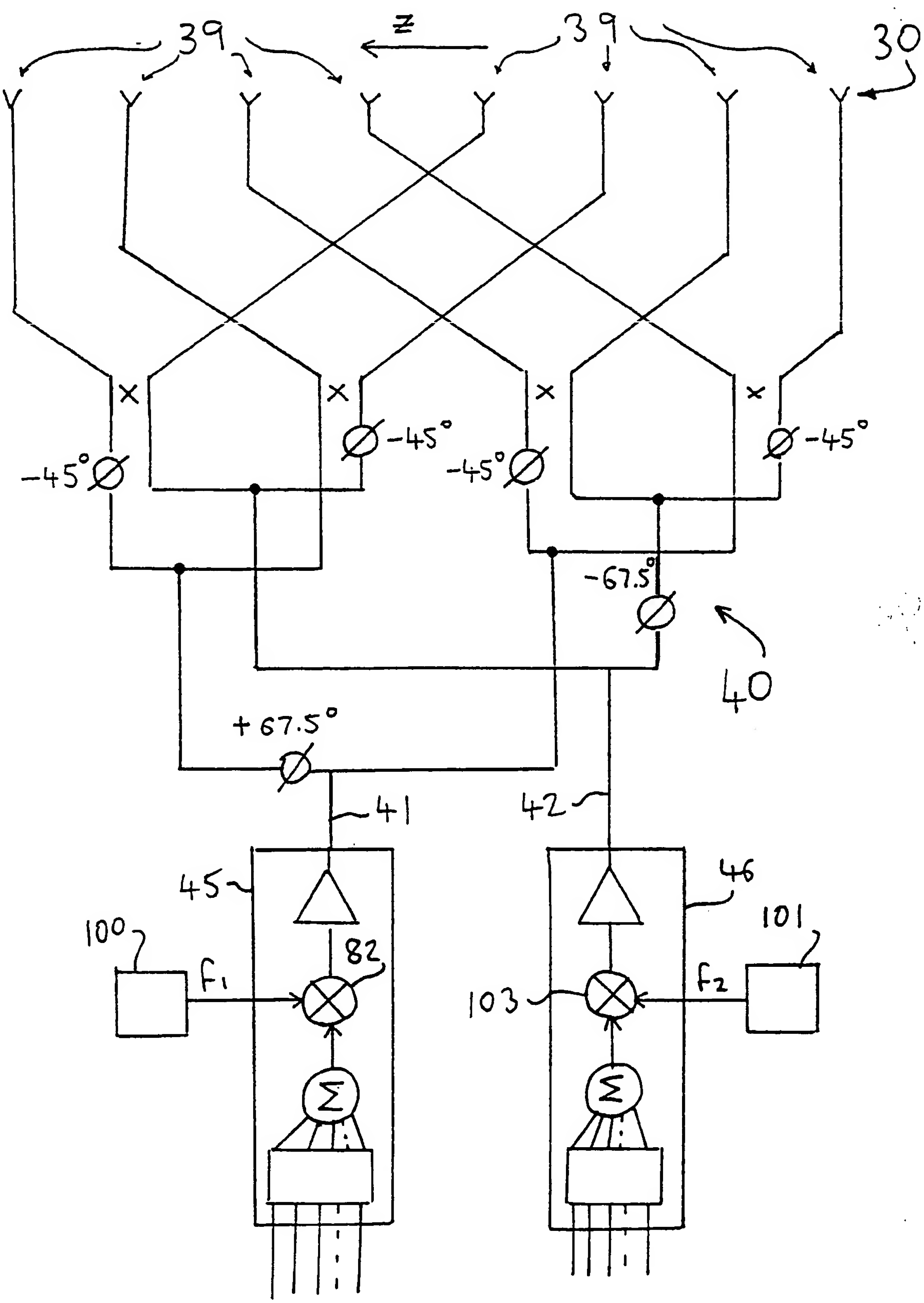


Fig. 12

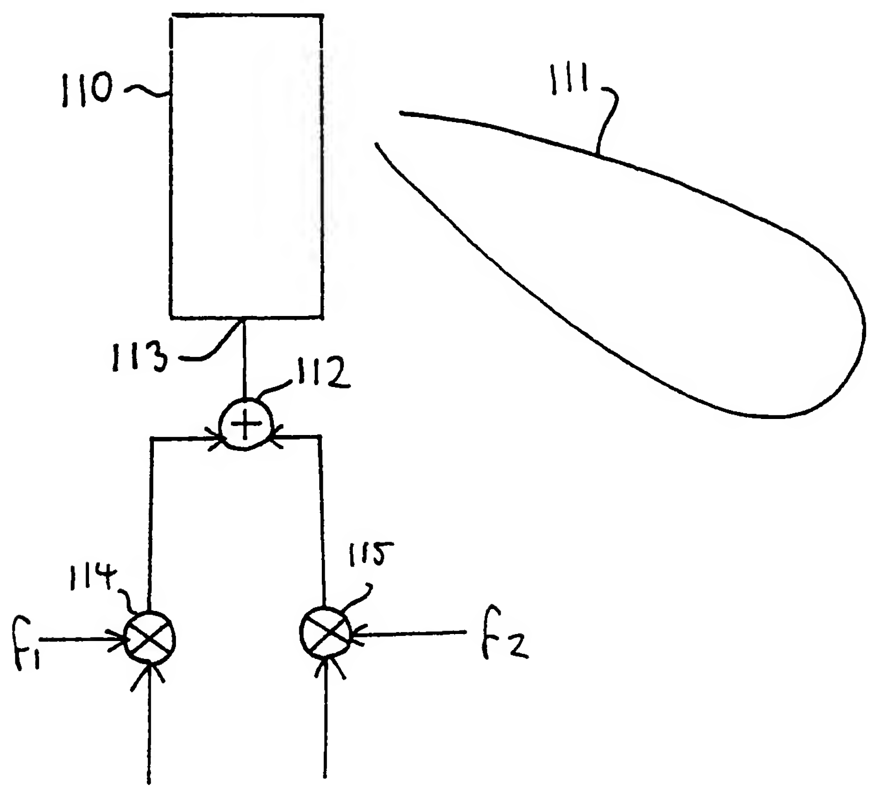


Fig.13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ00/00205

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: H01Q 1/36, H01Q 3/30, H04Q 7/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q 1/-, H01Q 3/-, H04Q 7/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT, USPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5551060 (Fujii et al.) 27 August 1996. See Figures 5A to D, column 3 and 4.	1-38
X	US 4638317 (Evans) 20 January 1987 See the whole document.	39,40

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
1 December 2000

Date of mailing of the international search report
12 DEC 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ00/00205

Box I **Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos :

because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos :

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos :

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II **Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims

2. [X] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

See separate sheet; Continuation of BoxII.

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box II:

Claims 1 to 10 define a method of communicating between a multi-beam phased array antenna and a plurality of mobile communication devices at different distances from the antenna where antenna elements are mounted at different heights. An upper beam communicates with the further of the mobile devices, where a downtilted lower beam communicates with the closer mobile devices.

Claims 11 to 38 define an antenna system including a plurality of antenna elements, a first and second transmitter for transmitting down-link signals and a phased array feed network. The feed network has means for providing a phase shift between antenna ports and first and second signal ports. The antenna elements are mounted at different heights and each element radiates an upper and a lower beam.

Claims 39 and 40 define a phased array feed network including a plurality of antenna ports, a plurality of signal ports, means for providing a phase shift between signals at the antenna ports and the signal ports, where the number of signal ports is less than the number of antenna ports.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/NZ00/00205

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	5551060	JP	5063634	EP	531090

END OF ANNEX